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FEASIBILITY STUDY : TEXTURE MAPPING GROUND AND AIRBORNE VIDEO ON A DIGITAL TERRAIN MODEL FOR VISUAL ANALYSIS OF FOREST CONDITIONS

by
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FEASIBILITY STUDY: TEXTURE MAPPING GROUND AND AIRBORNE VIDEO ON A DIGITAL TERRAIN MODEL FOR VISUAL ANALYSIS OF FOREST CONDITIONS

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ROCKY MOUNTAIN FOREST SERVICE AND RANGE EXPERIMENT STATION

FOREST PEST MANAGEMENT METHODS APPLICATION GROUP

FINAL REPORT: DECEMBER 1990

prepared by Ian D. Bishop and Eric Flaherty, Visualization Laboratory, College of Architecture, Texas A&M University

This research examines the feasibility of simulating the visual effects of forest pest infestation based on texture mapping live video onto three dimensional elevation models of landforms. This report is in three parts:

1) the accompanying videotape, and text to be read in conjunction with the videotape

2) the paper prepared for the Proceedings of Resource Technology '90

3) recommendations for further research

In general, we were very encouraged by the results of this initial feasibility study. The problems addressed in Part 3 all appear solvable and much high quality simulations can be generated with further system development. Particularly pleasing was the initial effects generated by tying the simulation process to our surrogate pest model. This direction is ripe for further exploration.

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PART 1: TEXT TO ACCOMPANY VIDEOTAPE

PROCEDURES

The USDA Forest Service provided several airborne video sequences of the Sanborn Park quad sheet in Colorado. These sequences included 1 mile (1.6 km) wide passes, a half mile (0.8 km) wide pass, and a quarter mile (0.4 km) wide pass. They were recorded using S-VHS tape, which has a horizontal resolution of 400 lines. This resulted in an approximate pixel size of 4 m on the 1.6 km strips, 2 m on the 0.8 km strip, and 1 m on the 0.4 km strip. Tape sequences 1 and 2 show sections of the video given to us. Although the sequences have transferred somewhat brighter than they appeared on the original video, they still illustrate two important problems in aerial video photography. The first is the changing terrain brightness levels which cause the camera's iris to change, causing moments of washed out video image. This can be corrected by manually setting the iris before a flyover. The second is the erratic yawing motion of the plane. When a texture map is assembled from still frames selected from these flyovers, the frames must be rotated to account for the movement of the aeroplane.

USGS elevation data and stand classification data were acquired for the same area. The elevation data was available on a 30 m grid. The stand classification data was available on a 15 m grid. A three dimensional object representing a 2.8 X 4.0 km area was created using the digital elevation data. Still frames from two of the 1.6 km wide passes were copied from S-VHS tape to an Abekas A60 digital frame store, with some color correction using a Nova 700 digital time base corrector. This was done to overcome the problems with the changing luminosity and chrominance mentioned earlier. Still frames which overlapped were then transferred to local disk space and converted from the Abekas' YUV format to Vista format to facilitate transfer between software packages. A paint and image enhancement package called Artisan was used to composite the stills into one large image. Finer color correction was done at this level to match the colors of the two passes. The resulting 1064 X 1528 pixel image was converted into a 2 K (2048 X 2048 pixel) color texture map using Wavefront, an animation package. A program was written to apply this texture map to the land form object representing the same area. Wavefront's Preview model was used to create a flyover of the area. This data was then sent to Wavefront's Image module, which renders the final video frames. Rendering times averaged 3 minutes per frame on a dedicated Silicon Graphics Power Iris 4D / 240 GTX. Videotape sequence 3 shows the flyover of the generated object.

Once the process of extracting, combining, and displaying the data was accomplished, the problem of visually simulating pest infestation was addressed. A model was developed to simulate the infestation and spread of mountain pine beetles in ponderosa pine. Such infestations begin in a few trees and then spread to infect around 70% of the trees in a given stand area. The trees go through color changes as they die from the infestation: pale green, yellow-green, russet red, and finally, gray (when the needles drop off).

The program which applies the texture map to the landform object was modified to take into account the stand data available from the USDA Forest Service. Ponderosa pine stands were identi-

fied, and a program written to simulate pest spread based on the above model. This program generated an array of numbers representing "infestation levels" (from 1 to 5) at each grid cell on the landform object. This array was then used to select an appropriate texture map for that cell when the object was rendered. Texture maps for each level of infestation were generated by two color correction techniques (discussed below) applied to the original map. The pest spread model generated infestation data over time so that a video animation could be created.

Two methods of color correction were used to create the necessary texture maps. Tape sequence 4 shows the effects of the first method. It involved writing a filtering program which would change all pixels in an image which fell in a certain RGB range to a different value. For the pale green map, roughly equal amounts of red, green, and blue were added. For the yellow map, red and green were added. For the red map, red was added. For the gray map, RGB values were equalized. The rendered frames show the progression of the infestation by selecting the appropriate map for a given cell in at a given point in time. Frames from one time period to the next were cross-dissolved using Wavefront's compositing module.

The second method of color correction involved using masking and tinting tools available in the Macintosh PixelPaint Professional software. Ranges of colors were selected using the dropper tool to build a mask over areas which were to be excluded. Tinting was then applied to the unmasked areas to achieve the necessary color effect for each of the infestation stages. The resulting maps were then applied and rendered using the procedures outlined above. Tape sequence 5 shows this method. Movement of the camera did not allow the frames to be cross-dissolved from one time period to the next, causing the changes to "pop" into the scene. Once the camera stopped moving, frames could then be cross-dissolved as before. The steps necessary to dissolve from one moving camera sequence to another involve rendering twice as many frames.

USING VIDEO IMAGERY AS TEXTURE MAPS FOR MODEL DRIVEN VISUAL SIMULATION

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ABSTRACT

A technique for visualization of forest pest infestation based on texture mapping is described. USGS digital elevation models, airborne video flown by the USDA Forest Service, digital image manipulation techniques and commercial rendering and animation software are used to generate realistic fly-over images of forested terrain. A texture library made from airborne video of different resolutions and texture selection software based on 'camera' distance and angle permits effective representation from different view levels. Generation of additional library textures reflecting different stages of tree deterioration permits texture selection for each ground polygon to correspond to forest stand based pest spread prediction models. Random selection of the first affected trees within affected stands and a within-stand cellular automaton style spread model for mountain pine beetle permit time based simulation of stand infestation and deterioration.

INTRODUCTION

Several computer based approaches to presentation of the natural landscape, and simulation of landscape changes, are currently under development and refinement. The first approach involves perspective generation from geographic information system based data on terrain and landuse. This was pioneered by Myklestad and Wager (1977) and has now developed to the level of sophistication described and illustrated by Heasley & McNamara (1990 - this volume). A more recently developed approach involves alteration using video processing techniques of images captured from selected view points in the field. Brian Orland both initiated this direction and best represents the current state-of-the-art (see Orland et al, 1990 - this volume). The research described here suggests a third approach which promises advantages, in particular circumstances, over either of the other techniques.

In conjunction with the USDA Forest Service we are exploring the use of a process called texture mapping, and a variant called bump mapping. Texture mapping is a computer process for covering the surface of a solid object with a two dimensional image taken from some other source. In this research the solid object is the ground surface - or the surface defined by the tops of the trees - and the textures are provided by video imagery. The imagery may be either current conditions - as captured on site - or predicted conditions using either (a) imagery from another site, or (b) imagery created using image processing techniques to show changes in tree condition.

A single texture can be applied across a large undulating surface and views of that surface generated from any angle. For some kinds of land use in which elevations above ground level are small this single mapping is adequate to provide both aerial views of existing conditions. When the viewpoint comes closer to the ground surface a problem of texture resolution arises, as a small number of original image pixels are spread across a larger number of screen pixels, unless highly detailed texture maps are available. Such maps are not only expensive to obtain but would consume vast amount of computer disk space if used over a large area. In the forest environment there are other potential problem for low level or ground based imagery. The mapping procedure becomes more complex because of the height of the trees and the effect this has on (a) differences between horizontal and vertical views of the same location, and (b) the potential for hiding of a location by trees closer to the observer.

These problems can be solved by intelligent (on the computer's part) selection of the scale/resolution of the texture to be used, of when to use textures derived from horizontal or vertical views, and by using canopy level as the elevation at which to apply the mapping in certain cases. Output from process models e.g. pest infestation, can be incorporated into the procedure by using model generated values to choose the textures, from a library of suitable imagery, to be applied.

These techniques provides potential advantages over both the 3D modeling approach and the 2D imaging approach to representation of forest conditions. In particular, it will permit the use of actual site specific imagery in conjunction with the animation capabilities inherent in 3D modeling.

PROCEDURE

Both USGS digital elevation data and airborne video were available for the Sanborn Park quad sheet in Colorado. The airborne video had been flown, by the USDA Forest Service, predominantly in 1 mile (1.6 km) wide strips but some sections were also available at half mile (0.8 km) and quarter mile (0.4 km) resolution. The recording medium was S-VHS with a horizontal resolution of 400 lines giving an approximate pixel size of 4 m on the 1.6 km swathe, and 2 m and 1 m on the lower altitude runs (Figure 1). The elevation data (DTM) was on a 30m grid. Forest stand classification was also available and was transferred to us on a 15 m grid.

A section of the quad sheet in which (a) a distinctive pattern of relief existed, (b) there were clear transitions from open to forested lands, (c) video material was available at all three scales and (d) there was clear overlap between 2 of the 1 mile swathes was selected for initial system development. The chosen area was roughly 2.8 km wide and 4.0 km long and covered part of the Sanborn Park property and a section of Horsefly Creek to the north. The terrain was therefore essentially flat, at an elevation of 2400 m, except where it dipped steeply about 350 m to the creek bed.

A succession of frames from each flying pass over the area were copied from the S-VHS tape onto an Abekas A-60 digital frame store. Some initial color

correction was done using a Nova 700 digital time base corrector to roughly match the chromanence and luminance of the frames from each pass. Frames, with minimal overlap, were selected by scanning the digital frame store and were then transferred to a local file server. They were converted, using our own programs, from their original Abekas (YUV) format into Vista (VST) format which provides ready transferability between software packages. The conversion process expanded each frame to 756 x 486 pixels and the frames for each pass were combined into larger images using a paint and image enhancement program called Artisan. Two 1.6 kilometer wide passes were combined and after edge trimming required because of the changing orientation of the aeroplane the result was one 1064 X 1528 pixel image covering roughly 2.8 X 4.0 kilometers. Frames from the 0.8 kilometer wide pass were combined into two images, one 629 X 1930 and the other 572 X 1621 pixels. Only the latter was used for the illustrations in this paper. Similar combination procedures were also applied to the 0.4 km pass. The greater the variation in flight direction the more a run needs to be broken down into image sections to avoid large losses of data to cropping. This variation was more prevalent in the low altitude flights.

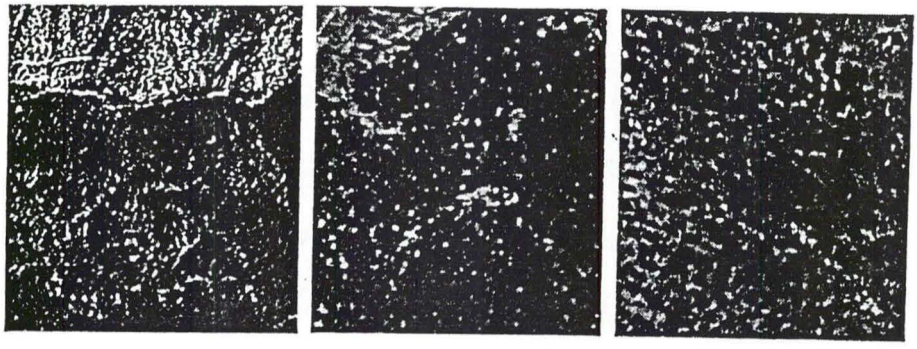

Figure 1. Sections of each of the composite textures based on the (a) 1.6 km, (b) 0.8 km and (c) 0.4 km overflights. The increasing resolution of the lower altitude flights is clear in the degree of isolation of individual trees.

In order to better match colors on the three sets of aerial images additional corrections were done using Artisan's color adjustment facilities. The resulting files were output in Vista format and then converted into texture maps using Wavefront's texture map utility. Wavefront requires that textures be square - in terms of pixel size - and the least loss of resolution is therefore achieved by using source images which are of similar dimension to the permitted texture sizes (i.e. 512, 1024 and 2048 pixels square). The long thin strips of composite image produced by the single lower altitude flight lines were therefore not conducive to efficient texture mapping. The images were initially stored as two megabyte textures but later also converted to one

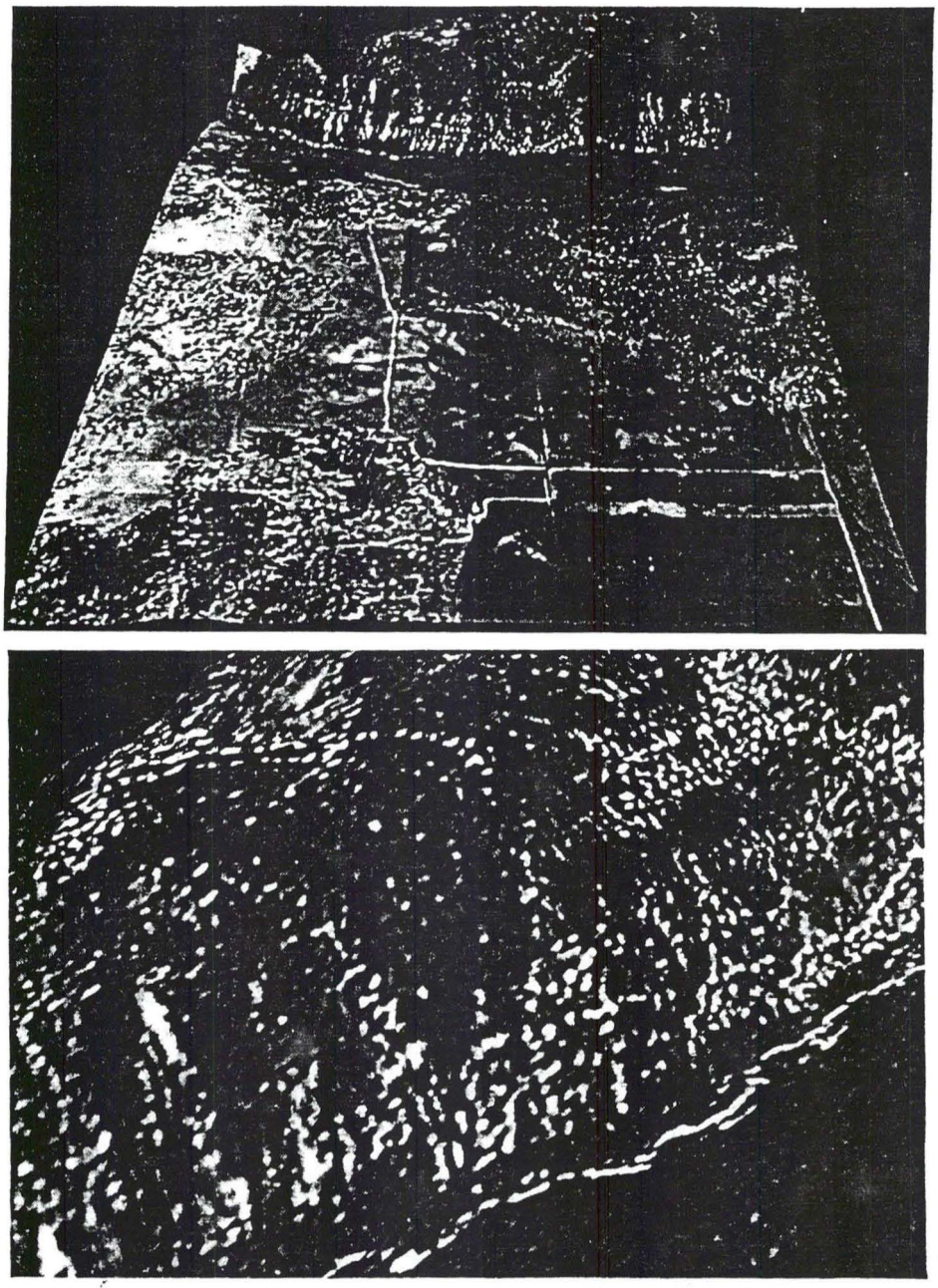

Figure 2. Rendered frames based on the 1.6 km wide overflight textures. From a distance (a) the resolution is adequate with trees appearing as massed clumps, the valley of Horsefly Creek quite distinct and major features such as the homestead, roads and different cropping areas visible. When the 'camera' is within the valley (b) and closer to the surface the problems of lack of texture resolution become clear.

megabyte textures because of storage requirements and savings in rendering time (a two megabyte resolution file requires over 16 megabytes of disk storage; a one megabyte file requires only 4 megabytes).

The UTM coordinates for the corners of each texture map were extracted by visual comparison with the USGS orthophoto quad sheet. This was made more difficult by the age of the orthophoto (1978), subsequent clearing and regrowth in the area, and the lack of distinctive landmarks in the landscape. A program was written to take these coordinates, extract the elevation data from the USGS digital elevation file and write out the required data in Wavefront object format. Each cell was divided into two triangles to ensure that all faces were planer for rendering purposes.

A new program was developed to apply the most appropriate texture maps onto an extracted grid base. This takes the camera position, as defined in Wavefront's Preview module, and selects a texture for each polygon depending on the distance between camera and polygon. This allows the use of higher resolution textures on polygons that are closer to the camera. Threshold distances were chosen such that a higher resolution image, if available, was chosen when the coarser image began to look smeared. Because the higher resolution flight lines did not overlap with the 1.6 km wide images in the area chosen it was not possible to test this capability on the Sanborn Park data.

Once the elevation data and surface textures have been define in Wavefront compatible format display parameters must be specified. These include the position and orientation of lighting, camera aspect ratio, equivalent focal length and camera position and orientation. The camera position and orientation can be altered through time to create a fly over. The Wavefront Preview module is used to prepare a file defining these parameter over a sequence of frames.

The Image module of Wavefront is then used to render each frame of the defined sequence. Rendering times were typically 3 minutes per frame on a Silicon Graphics Power Iris 4D/240GTX. Figure 2 shows two such frames for the study area. Rendered frames are copied from the file server back onto the Abekas. From there, they can be edited and transferred onto video-tape in any of several formats.

LINKAGE TO PEST MODELS

The USDA Forest Services models for prediction of pest infestation are based on stands of vegetation judged to be homogeneous with respect to species, age and their watershed (White & Heasley, 1988). They are usually limited to about 40 acres maximum area. The models predict the degree of infestation of each stand at each time interval. They can be run forward or backward in time.

No pest modeling has yet been done on the Sanborn Park area and so it was necessary to simulate some typical model output to judge the potential linkage to the texture mapping process.

Information derived from the forest stand number can be incorporated in several ways. In the simplest case, forest stand information is used to assign colors to the underlying surface. These 'show through' the applied textures and thus highlight the different stands in the area according to some set of criteria (such as output from a pest model). While this approach is simple and potentially effective in densely timbered areas, it was not suitable in the case study landscape because cleared grassy areas and ground visible between trees was also recolored. It is preferable, in the context of pest spread modeling, that only the trees themselves be recolored. This involves digital analysis of the video images to determine the color characteristics which visually distinguish trees from other ground cover. Once a digital process of identification is in place color balances can be altered to reflect different infestation and tree health conditions. The application of such digital image filters is described by Orland et al (1990 - this volume) in the context of ground level video based simulation. When texture maps representing different tree conditions have been prepared, another program uses the stand identification data to select from this texture library the appropriate texture for each face. This library contains multiple versions of each texture map each with colors in the forested areas adjusted to simulate different stages of pest infestation.

In the case study area the predominant species is ponderosa pine and the problem pest is mountain pine beetle. This beetle does not typically infest every tree in a stand. It begins in a few trees ('seed points') spreads to nearby trees and may eventually kill as much as 70% of a stand. The trees first fade to a pale green, then to a yellow-green before turning russet red and finally dropping their needles and assuming the grey appearance of dead pines.

Two approaches to color alteration were used. The first sought to automate the filtering process while the second was more interactive and, in this instance, more effective. In the first procedure, the characteristic colors of healthy trees were determined by using the color identification procedures in the Artisan software. Ranges of red, green and blue (RGB) values were determined which effectively distinguished the trees from the underlying grass. The texture map was then read into the filter program and whenever a pixel fell within the specified RGB range it was transferred to a corresponding position in a target RGB range with separate normalization for each of the R,G and B values. To achieve the pale green we added roughly equal amounts of red, green and blue; to get yellow, additional red and green were added; russet involved adding red and subtracting green and grey required equalization of the tree color components. Thus, including the healthy condition, five texture maps were prepared. While these procedures could be effective, the long turn around time (2-3 minutes) between setting of filter ranges and observation of results made experimentation difficult. A more direct procedure was made possible by the special masking and tinting tools available in the PixelPaint Professional software for Macintosh. After file conversion from Vista (VST) to the Macintosh PICT format, dragging the 'Dropper Tool' over the various colors to be left unalterted formed a mask

wherever these colors appeared in the image. If any area was missed it could be added to the mask by repetition of the procedure. A color was selected and applied as a tint over the entire texture rectangle. Masked areas were left unaltered and the remainder tinted in the chosen direction. In some cases it was also necessary to apply the 'Lighten' option to the treed/unmasked areas.

These procedures were applied over the entire texture maps because the texture allocation program distinguishes between forest species and selects areas within stands for infestation.

The texture selection process is based on the elevation grid points which define the terrain. In addition, points on the textures corresponding to each grid point must be defined. These are called the texture vertices. A facet of ground surface is defined by three grid points and three corresponding texture vertices. In addition, the texture to be used is specified for each facet. Because, in the examples chosen, the grid points used were 60 or 30 m apart more than one tree fell within a polygon and consequently the simulated infestation was somewhat coarser than reality would dictate. The process consisted of:

(a) determine the stand membership of each grid point;
(b) if the stand is not ponderosa pine then specify healthy texture;
(c) if stand is pine and
    (i) already dead then leave as grey texture
    (ii) russet then change to grey
    (iii) yellow then change to russet
    (iv) pale green then change to yellow
    (v) healthy then change to pale green if either
        - a random number is above new seed point threshold, or
        - adjacent grid point is affected, but not dead, and random number is above spread threshold
(d) repeat for next time period.

Independent specification of seed point and spread thresholds allows the model to be adjusted such that the mix of new seed and spreading areas can be matched to observed infestation patterns in other areas.

Figure 3 shows output this process for the study area. Animated sequences were then made for the large area with 1.6 km aerial coverage based on the automated color filter technique and for the smaller area with 0.8 km coverage with the interactive coloration techniques. The images were compared with examples of oblique aerial photography from infested sections of the same forest region. The first animation looked rather as though translucent patchwork squares were being placed one-by-one on the landscape.

This might be a useful representation for the forest scientist requiring an interpretation device but did not approach the level of visual reality we sought. The second animation was considerably more effective although more work is still required to achieve the subtlety of shading found in the real world and to effectively separate infested trees from their healthy neighbors (Figure 4).

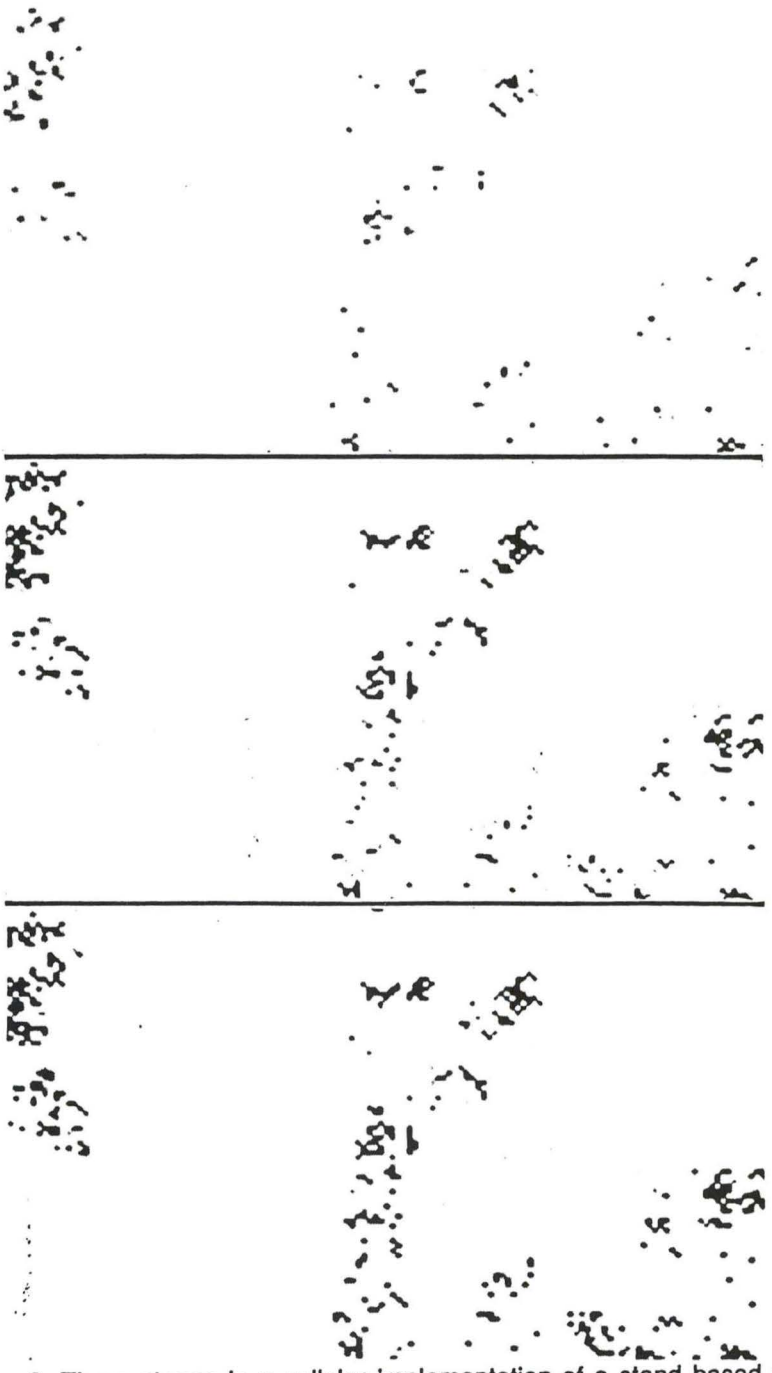

Figure 3. Three stages in a cellular implementation of a stand based spread model. Potential infestation levels are determined on a stand-by-stand basis and the process of transition to these levels based on cell-by-cell seeding and spread rules.

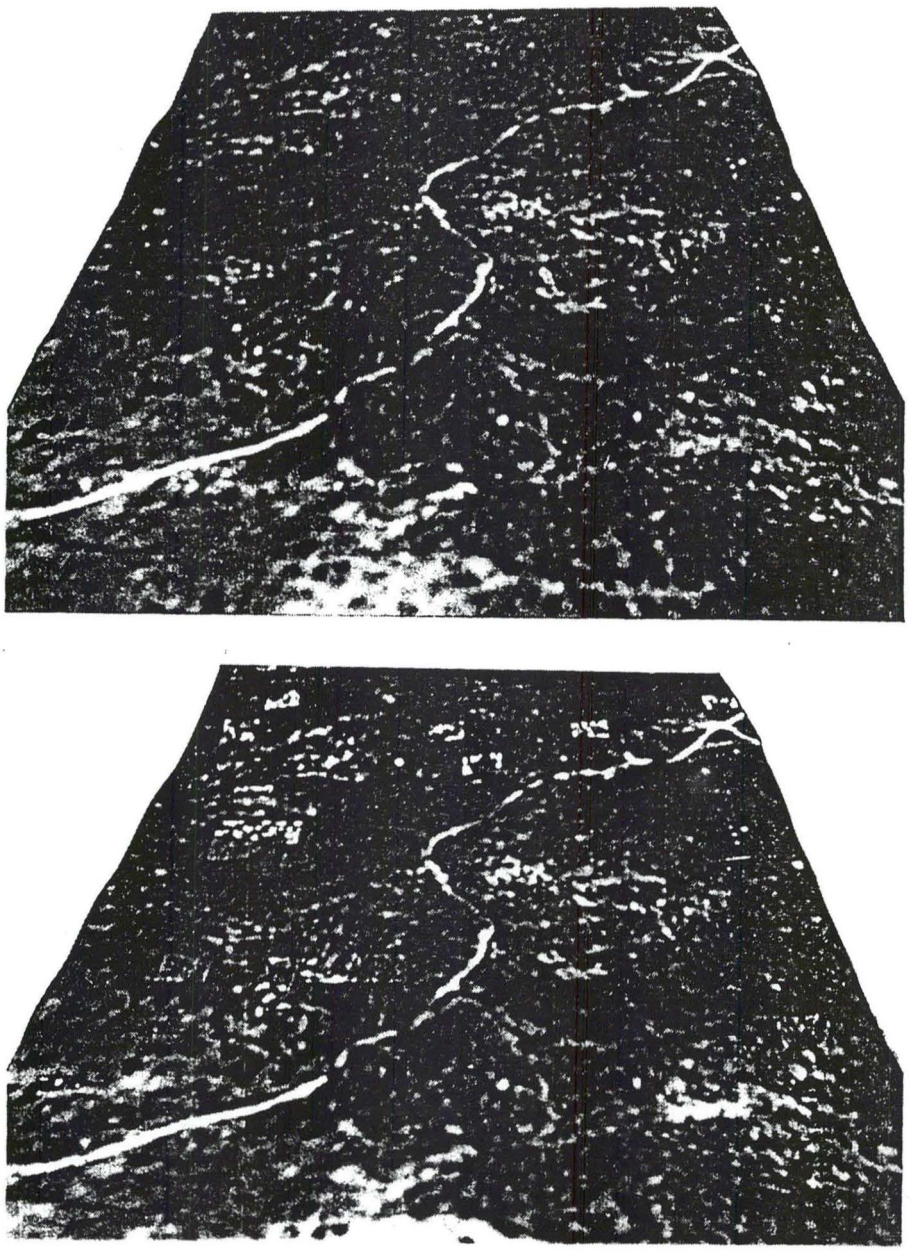

Figure 4. The pest spread model applied to a rendered frame based on the 0.8 km wide textures. In (a) there is no infestation in (b) it is well advanced. The contrast in (b) has been enhanced to show the restriction of the recoloration to tree masses using filtering techniques.

CONCLUSIONS

The techniques described show great promise for realistic simulation and animation of pest spread in forest regions. It becomes possible to simulate effects in areas which have not been recently visited and provides a more realistic result that wholly computer generated images.

The potential to move over, and eventually through, affected areas as if on a motor tour or paddling a canoe down stream provides both an effective presentation medium for policy makers and a research tool for assessment of visual impacts on the non-stationary observer.

ACKNOWLEDGEMENTS

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PART 3: ASSESSMENT AND RESEARCH DIRECTIONS

Some of the directions foreshadowed in the original research proposal have not yet been properly explored. In particular, it was anticipated that more time would be spent dealing with issues of the changing resolution and orientation requirements of textures. It was with this in mind that video sequences from three different height were chosen from the Forest Service collection and that ground level textures were collected for a variety of species and forest conditions.

This was not adequately explored because (a) in the subsection of the data area chosen to apply the techniques the different resolution video sequences were found not to overlap - contrary to expectations, and (b) it was decided to spend additional time exploring mechanisms for linking the pest modeling process into the simulation procedures. The latter was quite successful but the time spent left a gap in exploration of other system requirements.

In order to extend the procedures developed to date it is necessary to further research the following:

1. The Texture Mapping Process

(a) integration of different resolution grid bases and texture maps into a single data base permitting exploration of visual effects over a range of elevations above the surface;

One problem with texture mapping is that the resolution of the texture map must be very high in places where the camera comes close to the surface. This is especially true in animations where the camera is not moving. A future direction would be the use of higher resolution texture maps in areas where the camera approaches the surface. In addition to selecting a texture map by infestation criteria, it could also be selected based on distance and angle from the camera. This assumes that airborne video of the same area from different altitudes is available.

Another problem is the size of the underlying polygonal grid. For this simulation, grid data was only available in 30 m resolution. This causes the color alterations to appear as quite noticeable square patches on the surface. While this may be fine for a less realistic visualization model, it would, in many cases, be more desirable to have a higher resolution grid. This would result in a better looking image. This could be achieved by simply re-sampling the grid at a finer resolution but the size of the generated data base would present its own problems of longer CPU times and higher storage requirements.

(b) use of canopy elevations as the mapped surface in heavily treed areas and use of oblique or ground based textures on vertical faces permitting exploration of visual effects over a range of orientations to the data set;

Texture maps are essentially flat images wrapped around a three dimensional surface. This flat-

ness becomes obvious as the camera approaches the surface at a low angle. This requires that the animations do not use low camera angles, or that some other method of modeling the surface be employed to account for this.

(c) rectification of the airborne video images to deal with variations in flight orientation and permit better fit of image-to-image and also of image-to-ground;

Movement of the plane causes problems with lining up the resulting texture maps with each other and with the digital elevation model. Since maps are built from several still frames from video, any side-to-side movement, or veering from a straight flight path causes the maps to be rotated out of alignment with each other. This is especially pronounced at lower altitudes, where a slight angular variation causes a major change in the image orientation. An additional problem is that digital elevation data is based on a north/south grid pattern. Flight paths which do not follow these bearings generate texture maps which must be rotated again to match the grid orientation.

(d) development of systems for dealing with artificial color differences between source images.

Flyovers of the same area at different times tend to have different colorations due to cloud cover, change in solar angles, shadows, and other factors. Several steps of color correction must be done to match up disparate images. Gross color correction can be done at the video transfer phase using video color correction equipment. Finer correction can be done on the images once they are in the computer using image enhancement software.

Much of the necessary software for (a) and (b) has been written already. It needs to be tested and further developed: (c) and (d) are new initiatives arising from our experience in the feasibility study.

2. Linkage to pest or other dynamic models

(a) improved techniques for creation of textures representing different infestation levels of different pests in difference host species;

(b) better control of the temporal aspect of the pest spread simulation;

(c) development or collection of textures representing different pest management options; and

(d) experimentation with a more direct tie to the pest spread models.

Here (a) and (b) are extensions of what we have learned so far in this research; (c) represents an obvious extension and parallels the works of Heasley and Orland using other techniques; while (d) will require some closer collaboration possible through INFORMS and Doug Loh's work.

3. Other directions

As these problems are being solved the opportunity exists to explore other applications of this new technology. Some areas to be considered include:

(a) use of texture mapping and other computer animation devices in conjunction with aerial spray dispersion models;

(b) use of the simulations in training and management aspects of Forest Pest Management; and

(c) the transfer of aspects of the simulation system to lower cost equipment and more accessible software.